J. Anat. (2007) **211**, pp630–638 doi: 10.1111/j.1469-7580.2007.00801.x

Human 2D (index) and 4D (ring) digit lengths: their variation and relationships during the menstrual cycle

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Abstract

It is known that there are sexually dimorphic differences in relative and absolute lengths of the index (2nd) and ring (4th) fingers and that the sizes of laterally-paired soft tissues (e.g. ears and fingers) show changes across the menstrual cycle. The aim of the present study was to determine whether cyclical changes in the digit lengths of the index and ring fingers also occur and, if so, to what extent these are related to changing patterns of circulating sex steroids. Digit lengths were assessed over two cycles in groups of right-handed females (19–21 years of age) who were divided on the basis of whether or not they were taking oral contraceptive pills (n = 13 and n = 6 respectively). Using callipers, finger lengths were measured on photocopy images of both hands taken at 4-day intervals for a total of 56 days. We tested the following null hypotheses: (1) digit length measurements do not exhibit fluctuations across the menstrual cycle; (2) there is no evidence of lateral asymmetry between measurements made on both hands; (3) the lengths of digits 2 and 4 do not differ in either hand. Null hypotheses were tested using Page's L trends test for related samples (cyclical fluctuations) and paired Student's t tests (left–right asymmetries and within-hand digital differences). In those not taking oral contraceptives, finger lengths and 2D:4D digit ratios fluctuated across the cycle with values tending to increase in the pre-ovulatory period and decline thereafter. Left–right asymmetries varied in a similar fashion with lengths generally being larger, and lateral asymmetries smaller, in the dominant hand. Although sample sizes were smaller, some of these patterns were retained but others were perturbed in those practising oral contraception. We conclude that finger lengths are cycle-dependent and that account should be taken of this, and of oral contraceptive usage, in future studies on female digit lengths and their ratios.

Key words digit length; index finger; menstrual cycle; ring finger; 2D:4D ratio.

Introduction

In addition to the obvious anatomical differences between males and females, more subtle sexual dimorphisms also exist. Evidence from human studies demonstrates that the length ratio of index finger (second digit, 2D) to ring finger (fourth digit, 4D) exhibits a sexually dimorphic pattern with males tending to have a 2D:4D ratio of less than 1 and females a higher ratio which may be greater than 1 (Manning et al. 1998; Williams et al. 2000; Peters et al. 2002). Lower 2D:4D ratios in the right hand have been associated with higher sperm counts and blood testosterone levels in males whilst higher ratios have been associated with high blood levels of oestrogen, luteinizing hormone and prolactin in males and females (Manning et al. 1998). More controversially, it has been suggested that a smaller 2D:4D ratio in women is associated with a lesbian sexual orientation and that both traits reflect elevated levels of androgens early in development (Williams et al. 2000; Brown et al. 2002b). Recently, it has also been reported that gender differences in 2D:4D ratios are absent in adolescents with schizophrenic personality disorders (Walder et al. 2006). This raises the possibility that 2D:4D ratios might be used as a marker for traits associated with early disruption of the steroidal milieu. Consequently, understanding factors which contribute to variability in 2D:4D ratios is of considerable importance.

Consistent gender differences in various human populations around the world (Peters et al. 2002), and the occurrence of a similar sexual dimorphism in 2D:4D ratios in the hind–paw digits of mice (Brown et al. 2002a), suggest a biological rather than an environmental origin. Whilst a genetic origin, involving the isolated or interactive effects of *SRY* or *HOX* genes, cannot be discounted (Manning et al. 1998, 2004; Firman et al. 2003), differential prenatal

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Accepted for publication *7 July 2007*

and neonatal exposure to testosterone and oestrogen are considered the most likely explanation for the development of 2D:4D ratios in humans. Evidence exists that the sexually dimorphic pattern is established around 14 weeks prenatally and is fixed from the second postnatal year or later (Garn et al. 1975; Manning et al. 1998; Williams et al. 2003).

Since the human menstrual cycle is characterised by highly fluctuating levels of different hormones, notably oestrogens and progesterone, we have investigated the effect of the stage of the menstrual cycle on 2D:4D ratios. Since gender differences in ratios appear to be focussed on the dominant hand, we have also examined the lateral asymmetry of changes in 2D:4D ratios. It is known that the stage of the menstrual cycle is associated with alterations in the lateral asymmetries of paired soft tissues, breasts and ears (Manning et al. 1996). Asymmetry tends to be lower at the onset of menstruation, peak at about day 24 and then decline towards the succeeding menstruation. At mid-cycle, coinciding with ovulation, there is a marked increase then decrease in asymmetry over a brief (24 h) period. Similar changes around mid-cycle are seen in soft tissue traits associated with digits 3, 4 and 5 (Scutt & Manning, 1996). In addition, cyclical changes in cognitive ability have been reported. It has been found that high oestrogen levels during the luteal phase are associated with poorer performance in tests of spatial ability (Hampson, 1990; Moody, 1997; Phillips & Silverman, 1997; McCormick & Teillon, 2001). During this phase, women also perform worse than those taking oral contraceptives (McCormick & Teillon, 2001). Functional cerebral asymmetry changes in a way consistent with the notion that oestrogen has a depressive effect on right hemisphere function (Sanders et al. 2002).

The relationships between finger lengths and the stage of the menstrual cycle have not been investigated extensively (Scutt & Manning, 1996). The aim of this study was to test whether or not changes in the lengths of digits 2 and 4, and the ratios and differences between them, occurred during the menstrual cycle. To this end, we studied digit lengths over two cycles in groups of females (19–21 years of age) who were divided on the basis of whether or not they were taking birth control pills. We tested the following null hypotheses: (i) digit length measurements do not exhibit fluctuations across the menstrual cycle; (ii) there is no evidence of lateral asymmetry between measurements made on both hands; (iii) there are no differences between the lengths of digits 2 and 4 in either hand. We also examined whether or not the use of oral contraception perturbed normal patterns during the cycle.

Materials and methods

The studies were approved by the University of Nottingham Medical School Ethics Committee. Initially, 20 female medical undergraduate volunteers, 19–21 years of age, were recruited from Nottingham University Medical School. The purpose of the study was explained both verbally and in writing and all recruits were given the opportunity to ask further questions before self-consenting to participate. Each volunteer completed a questionnaire which sought information about the onset date of last menstruation (to estimate their menstrual cycle stage) and current oral contraceptive usage (to account for variations in hormone concentrations between students). All subjects were classed as dextral (right-handed) on the basis of volunteered informed about hand preference. The duration of the study was eight weeks to cover two separate menstrual cycles for every individual. One volunteer was withdrawn from the study due to lack of a suitably comprehensive dataset. Eventually, students were divided into two groups: those not taking oral contraceptives (the –OC group, $n = 13$) and those taking various types of oral contraceptive (+OC group, $n = 6$).

Hand photocopying

In order to obtain digit length measurements for all participants, photocopies of left and right hands were made. Photocopying has been shown to be effective in previous human 2D:4D studies (Manning et al. 2001; Peters et al. 2002; Rahman & Wilson, 2003). The method produces measurements which correlate well with those obtained directly from the hands with callipers (Robinson & Manning, 2000) and tends to give lower 2D:4D ratios but with enhanced inter-observer reliability (Peters et al. 2002; Manning et al. 2005). At least for the present longitudinal studies on the same digits, any relative biases should be equal and comparisons should retain their comparative worth. However, it has been suggested recently that photocopies may distort left–right asymmetries (Manning et al. 2006). Clearly, further studies are required, including direct measurements on digits, to test the possibility of such biases influencing outcome measures. For consistency, photocopies were made according to a strict protocol designed on the basis of a pilot study, which compared the effect of different hand positions on digit length measurements.

The pilot study was designed to test the null hypothesis that wrist position (abducted, adducted or straight) does not alter 2D or 4D length measurements for an individual. Twelve independent participants ($n = 6$ males and $n = 6$ females) were selected randomly from a set of medical undergraduates in the library of the University of Nottingham Medical School. The purpose of the study was explained and each student consented to partake. Any student who had fractured, suffered trauma to, or had arthritis in, their 2D or 4D was excluded and students were asked to remove any rings from these digits.

The photocopier contrast was altered initially so that the proximal crease and distal finger tip were clearly visible. Three photocopies were taken from each student, the first with both hands in full abduction (radial deviation) at the wrist, the second with both hands in full adduction (ulnar deviation) and the third with a straight wrist, such that a line drawn along the length of the third digit extended between the radius and the ulna. In each position, the lengths of 2D and 4D were measured from the midpoint of the proximal crease, to the distal finger tip point, using digital callipers accurate to 0.01 mm. Differences between the 2D and 4D measurements were calculated for each of the three photocopies. For any individual, the minimum difference between photocopies was 0.05 mm and the maximum difference was 3.00 mm.

Despite the small sample sizes, significant differences between length measurements of the same digit were found for the three different hand positions. These indicated that abduction at the wrist favoured the 2D and adduction favoured the 4D. In a larger study (see Peters et al. 2002), similar significant differences were established. On this basis, the third straight wrist position was selected for use in this study. This allowed us to avoid favouring either the 2D or 4D and maintained consistency between participants.

Having established a satisfactory protocol, we embarked upon the definitive study. The photocopier contrast was adjusted to a setting which produced a clear hand image, where both the proximal crease and distal finger tips of 2D and 4D were visible and distinct from the background. The female participants were asked to remove any rings or jewellery that might hinder measurements of 2D and 4D lengths from the proximal crease to the finger tip. Any participants who had previously fractured, suffered trauma, or had arthritis in the relevant digits were excluded from the study, along with participants who had been diagnosed with a condition affecting hormone concentrations, bone growth, or oedema. This was intended to remove potential confounding variables from the study.

Participants were asked to place the palmar surface of both hands on the photocopier, making full contact with the photocopy plate but without applying firm pressure. Adopting the method used by Peters et al. (2002), participants were instructed to hold their three middle digits straight and adducted (without overlapping) but with first and fifth digits slightly splayed. Their upper limbs were extended at the elbow with the third digit in line with the midpoint of the radius and ulna. The photocopier lid was lowered to avoid excessive light exposure and to improve image quality. After photocopying, the image quality was checked and, if necessary, the photocopying was repeated. All photocopies were on Mondays and Thursdays between 1–2 pm to minimise possible diurnal and circadian variations in digit lengths. Participants remained anonymous and the only other information taken was their age and hand preference. This was recorded on the reverse of the photocopy to conceal the information from the measurer.

Digit measurements

Identical digit length measurements were taken from every photocopy, using digital callipers accurate to 0.01 mm. To eliminate bias due to inter-observer errors, all digits were measured by one observer. The lengths of 2D and 4D were measured from the midpoint of each proximal crease to the distal finger tip. These measurements were used to calculate the 2D:4D ratio (obtained by dividing 2D by 4D length) and the 2D-4D difference (obtained by subtracting 4D from 2D). Another measure, referred to as the 'distal tip extent' (DTE) was taken. In effect, this affords a different method of estimating the 2D-4D difference and was adapted from the 'tip measure' described by Manning et al. (2000). A line was drawn between the midpoints of the 2D and 4D proximal creases to account for hand shape. Two further lines were then drawn parallel to this, one at the point of the 2D distal finger tip and one at the 4D distal finger tip. The distance between the 2D and 4D distal tip lines was then measured at 90° to the lines, giving the 'distal finger tip extent'. The purpose of using both the DTE and 2D-4D difference as outcome measures was to assess the comparative worth of alternative digit measures.

Where appropriate, measurements were averaged over both cycles so as to account for possible within-subject cycle-to-cycle differences.

Statistics

The mean, standard deviation (SD) and standard error of mean (SEM) were calculated for each group of subjects. To better describe subject-to-subject variation within groups, the observed coefficient of variation was calculated (oCV = SD/mean). Comparisons between digits on the same hand, and between the same digits on left and right hands, were drawn using paired Student's *t* tests (Sokal & Rohlf, 1981) and based on measurements obtained from both cycles. To test for differences on the same hand during different stages of the cycle, we applied Page's L trends tests for related samples (Miller, 1975). To this end, the menstrual cycle was divided into 7 stages each of which comprised an equal interval of time (4 days). Thus, the first stage of the cycle (marked from the onset of menstruation) covered days 1–4 and the last covered days 25–28. All statistical tests were undertaken using Unistat v5.5 software (Unistat Ltd, London, UK). For all comparisons, the corresponding null hypothesis was rejected at the $P < 0.05$ level of significance.

Results

Variance sources and their contributions

In the present study, the observed variation in finger length for a group of subjects (oCV) is determined partly

Table 1 The variation in primary and secondary outcome measures across the menstrual cycle. Each value is a group mean (CV) for n = 13 subjects not taking oral contraceptives (–OC group). DTE, distal tip extent; LH, left hand; RH, right hand

Measure	Days 1–4	Days 5–8	Days 9–12	Days 13–16	Days 17–20	Days 21–24	Days 25–28	*P* level
RH 2D mm	71.21 (0.067)	71.22 (0.068)	71.36 (0.071)	71.24 (0.066)	71.14 (0.066)	71.24 (0.066)	70.91 (0.068)	*
RH 4D mm	71.54 (0.071)	71.59 (0.072)	71.73 (0.073)	71.68 (0.076)	71.56 (0.073)	71.65 (0.071)	71.27 (0.074)	*
RH 2D:4D	0.996 (0.038)	0.996 (0.044)	0.996 (0.043)	0.995 (0.036)	0.995 (0.041)	0.995 (0.038)	0.996 (0.036)	NS
RH 2D-4D	−0.33 (8.13)	−0.38 (8.17)	−0.37 (8.30)	−0.44 (5.87)	−0.42 (6.84)	−0.42 (6.43)	−0.36 (6.94)	NS
RH DTE	1.27 (2.68)	1.04 (3.31)	0.61 (5.52)	0.99 (3.34)	1.09 (2.85)	1.64 (1.95)	1.35 (2.11)	**
LH 2D mm	70.25 (0.064)	70.29 (0.065)	70.47 (0.063)	70.37 (0.063)	70.34 (0.062)	70.29 (0.067)	70.00 (0.068)	*
LH 4D mm	71.47 (0.067)	71.28 (0.072)	71.60 (0.069)	71.41 (0.071)	71.57 (0.070)	71.55 (0.067)	71.26 (0.072)	NS
LH 2D:4D	0.984 (0.031)	0.987 (0.031)	0.985 (0.032)	0.987 (0.035)	0.984 (0.034)	0.983 (0.031)	0.983 (0.031)	*
LH 2D-4D	−1.22 (1.84)	−0.99 (2.24)	−1.14 (2.02)	−1.04 (2.38)	−1.23 (1.99)	−1.25 (1.77)	−1.26 (1.72)	NS
LH DTE	−0.14 (16.37)	−0.31 (6.78)	−0.33 (8.54)	−0.05 (57.21)	−0.38 (6.55)	−0.30 (8.47)	−0.28 (8.75)	NS
2D L-R mm	−0.96 (1.42)	−0.93 (1.50)	−0.89 (1.58)	−0.87 (1.37)	−0.80 (1.14)	−0.94 (0.88)	−0.90 (1.03)	*
4D L-R mm	−0.07 (14.9)	−0.31 (4.88)	−0.13 (11.1)	−0.27 (4.97)	0.01 (193)	−0.11 (12.5)	−0.01 (281)	*

Comparisons between cycle stages were drawn using Page's L trends test. NS denotes not significant, *$P < 0.05$ and **$P < 0.01$.

by the true variation between subjects (tCV) and partly by the introduced errors (i.e. the variation between cycle stages and the precision of measurement). Collectively, the introduced errors may be thought of as the study 'noise'. The relationship between these terms is given by:

$$oCV^2 = tCV^2 + nCE^2$$

where nCE^2 is the contribution which noise makes to observed variance (oCV^2) and tCV^2 is the contribution made by the natural or biological differences between subjects (the 'signal'). In a sensible study design, the noise should not exceed the signal. In fact, analysis of 2D lengths on the right hands of a random subset of n = 6 subjects, averaged over all cycle stages, yielded an estimated oCV^2 of 0.00370881. The average value of nCE^2 was estimated by repeat measurements on the same digits of the same subjects. The use of callipers which measured to the nearest 0.01 mm produced nCE values in the range 0.000944 to 0.00337, with a mean of 0.002366 and, therefore, an estimated nCE^2 of 0.000005598.

These variance estimates indicate that tCV^2 accounted for almost 99.9% of total variance whereas the introduced errors accounted for just over 0.1%. In other words, the primary outcome measures (finger lengths) in the present study effectively provided estimates of the true variation between subjects.

Differences over the menstrual cycle

In those not taking oral contraceptives (–OC group, Table 1), there were significant differences over the menstrual cycle in both hands. In the right hand, cyclical differences were found for 2D length ($P < 0.05$), 4D length ($P < 0.01$) and DTE ($P < 0.01$). Finger lengths tended to be greatest at about mid-cycle and lowest around menstruation (Fig. 1). In contrast, DTE values were smaller around

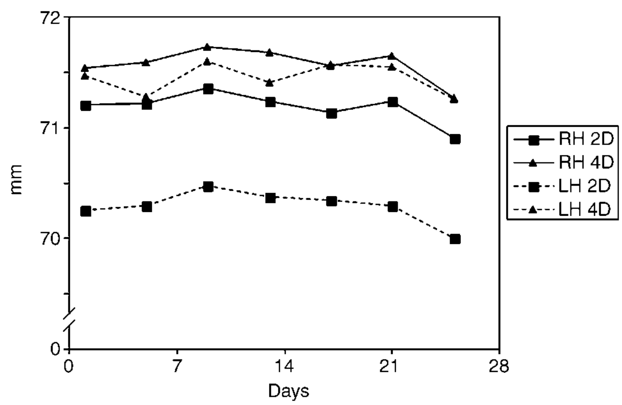

Fig. 1 2D and 4D finger lengths in right and left hands of women not taking oral contraceptives (n = 13).

mid-cycle. No differences in 2D:4D ratios or 2D-4D measures were detected. In the left hand, cyclical variation was seen for 2D length ($P < 0.05$) and 2D:4D ratio ($P < 0.05$) but not in 4D length, 2D-4D or DTE. Values of 2D finger length (Fig. 1) and 2D:4D ratio tended to be higher at about mid-cycle.

Lateral (left–right) differences in 2D and 4D lengths also showed significant fluctuations over the cycle. In the case of 2D ($P < 0.05$), the smallest lateral differences occurred around mid-cycle although 2D length in the right hand exceeded that in the left at all stages of the cycle. The pattern was different for 4D in that greater differences were seen before mid-cycle and smaller differences thereafter ($P < 0.05$, Fig. 1).

In all cases, the observed CV in digit lengths was small. Values at every stage of the cycle were in the region of 7% and this is indicative of a consistent and relatively low subject-to-subject variation. Interestingly, 2D:4D digit ratios had even lower oCV values (about 3–4%) at all stages of the cycle and this suggests that digit lengths are closely correlated or tightly regulated.

Table 2 The variation in primary and secondary outcome measures across the menstrual cycle. Each value is a group mean (CV) for n = 6 subjects taking oral contraceptives (+OC group). DTE, distal tip extent; LH, left hand; RH, right hand

Measure	Days 1–4	Days 5–8	Days 9–12	Days 13–16	Days 17–20	Days 21–24	Days 25–28	*P* level
RH 2D mm	68.86 (0.047)	68.43 (0.039)	68.87 (0.038)	68.90 (0.032)	68.68 (0.041)	68.80 (0.036)	69.13 (0.042)	**
RH 4D mm	70.31 (0.049)	70.17 (0.050)	70.37 (0.050)	70.31 (0.045)	70.23 (0.051)	70.61 (0.048)	70.31 (0.052)	*
RH 2D:4D	0.980 (0.030)	0.976 (0.039)	0.980 (0.039)	0.981 (0.035)	0.979 (0.033)	0.975 (0.040)	0.984 (0.041)	**
RH 2D-4D	−1.45 (1.43)	−1.74 (1.55)	−1.50 (1.82)	−1.41 (1.75)	−1.55 (1.50)	−1.82 (1.55)	−1.19 (2.43)	NS
RH DTE	0.18 (12.07)	0.08 (29.90)	0.07 (38.78)	0.51 (5.04)	0.14 (17.42)	0.28 (10.65)	−0.04 (78.74)	NS
LH 2D mm	69.48 (0.046)	69.09 (0.036)	69.12 (0.036)	69.78 (0.041)	69.27 (0.045)	69.92 (0.045)	69.41 (0.042)	*
LH 4D mm	71.08 (0.053)	70.90 (0.055)	70.71 (0.049)	71.02 (0.049)	70.73 (0.050)	71.16 (0.051)	70.86 (0.050)	*
LH 2D:4D	0.978 (0.016)	0.975 (0.030)	0.978 (0.030)	0.983 (0.022)	0.980 (0.022)	0.983 (0.018)	0.980 (0.028)	NS
LH 2D-4D	−1.60 (0.72)	−1.82 (1.25)	−1.59 (1.38)	−1.24 (1.23)	−1.47 (1.07)	−1.24 (1.02)	−1.45 (1.42)	NS
LH DTE	−0.82 (1.85)	−0.80 (2.56)	−0.66 (3.68)	−1.48 (1.17)	−0.63 (2.13)	−0.63 (1.82)	−0.69 (2.35)	NS
2D L-R mm	0.63 (1.06)	0.66 (1.20)	0.25 (3.63)	0.88 (1.26)	0.58 (1.39)	1.12 (1.18)	0.28 (2.69)	*
4D L-R mm	0.77 (1.79)	0.74 (2.13)	0.34 (5.55)	0.70 (2.34)	0.50 (2.81)	0.55 (2.75)	0.55 (2.97)	*

Comparisons between cycle stages were drawn using Page's L trends test. NS denotes not significant, *$P < 0.05$ and **$P < 0.01$.

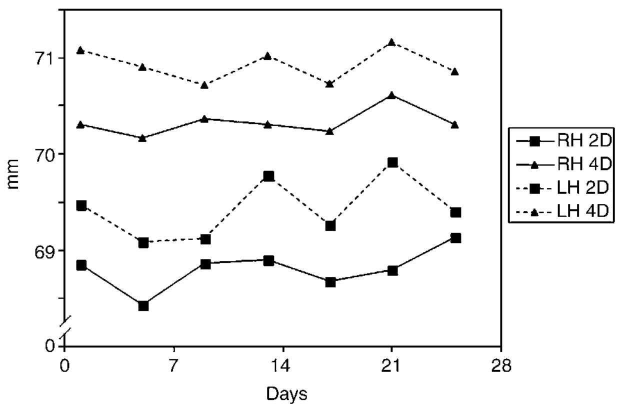

Fig. 2 2D and 4D finger lengths in right and left hands of women taking oral contraceptives (n = 6).

Somewhat different findings were made for those taking oral contraceptives (+OC group, Table 2). In the right hand, cyclical differences were found for 2D length ($P < 0.01$), 4D length ($P < 0.05$) and 2D:4D ratio ($P < 0.01$). Values of these measures tended to be greater after mid-cycle and towards the end of the luteal phase (Fig. 2). In the left hand, cyclical changes were seen in finger lengths only ($P < 0.05$ in both cases). Again, values tended to be higher after mid-cycle (Fig. 2).

As for the –OC group, left–right differences in 2D and 4D lengths also showed significant fluctuations over the cycle ($P < 0.05$ in both cases). However, for 2D, the smallest lateral differences occurred before mid-cycle and 2D length in the right hand was lower than that in the left at all stages of the cycle (Fig. 2). Again, the pattern was different for 4D but similar to that in the –OC group in the sense that greater differences were detected before mid-cycle and smaller differences thereafter ($P < 0.05$).

Again, oCV values for digit lengths were small (mostly 3–5%) and those for 2D:4D ratios even smaller (2–4%).

Table 3 Lateral asymmetry in measures of average finger length. Each value is a group mean (CV) for n = 26 averages (13 subjects × 2 cycles) for subjects not taking oral contraceptives (–OC group). DTE, distal tip extent

Measure	Right Hand	Left Hand	*P* level
2D mm	71.17 (0.066)	70.27 (0.063)	**
4D mm	71.57 (0.071)	71.43 (0.068)	NS
2D:4D	0.996 (0.038)	0.984 (0.031)	*
2D-4D	−0.40 (6.88)	−1.17 (1.88)	*
DTE	1.14 (2.72)	−0.23 (10.11)	**

Comparisons between right and left hands were drawn using a paired Student's t test. NS denotes not significant, *$P < 0.01$ and **$P < 0.001$.

Table 4 Lateral asymmetry in measures of average finger length. Each value is a group mean (CV) for n = 12 averages (6 subjects × 2 cycles) for subjects taking oral contraceptives (+OC group). DTE, distal tip extent

Measure	Right Hand	Left Hand	*P* level
2D mm	68.81 (0.038)	69.42 (0.040)	*
4D mm	70.34 (0.047)	70.95 (0.049)	NS
2D:4D	0.979 (0.035)	0.979 (0.023)	NS
2D-4D	−1.52 (1.57)	−1.53 (1.09)	NS
DTE	0.12 (21.21)	−0.78 (2.00)	NS

Comparisons between right and left hands were drawn using a paired Student's t test. NS denotes not significant and *$P < 0.05$.

Lateral (left–right) differences

Findings are summarised in Tables 3 (–OC group) and 4 (+OC group) and based on averages taken from all subjects and all stages of both cycles. For those not taking oral contraceptives, we found significant lateral differences in all variables except for 4D length. The 2D finger length

Table 5 Digital differences in measures of average finger length (mm). Each value is a group mean (CV) for $n = 26$ (–OC group, 13 subjects × 2 cycles) or $n = 12$ (+OC group, 6 subjects × 2 cycles)

Side	2D	4D	*P* level
–OC group			
Right Hand	71.17 (0.066)	71.57 (0.071)	NS
Left Hand	70.27 (0.063)	71.43 (0.068)	*
+OC group			
Right Hand	68.81 (0.038)	70.34 (0.047)	*
Left Hand	69.42 (0.040)	70.95 (0.049)	**

Comparisons between 2D and 4D in each hand were drawn using a paired Student's *t* test. NS denotes not significant, $*P < 0.05$ and $**P < 0.01$.

was significantly greater in the right hand ($P < 0.001$) and this hand also showed correspondingly greater 2D:4D ratios ($P < 0.01$). The 2D-4D difference ($P < 0.01$) and DTE ($P < 0.001$) also differed between left and right hands.

This pattern of lateral differences was not reproduced in the group taking oral contraceptives. Although we found significant lateral differences in 2D finger length ($P < 0.05$), the greater lengths were seen in the left hand. No significant lateral differences were detected for other variables.

Digital (2D vs 4D) differences

Findings for right and left hands are provided in Table 5. Again, values are averaged across all subjects, stages and cycles.

In the –OC group, there were no significant differences in length between 2D and 4D in the right hand. In contrast, 4D length was greater in the left hand ($P < 0.05$). For the +OC group, 4D length exceeded 2D length in both the right ($P < 0.05$) and left ($P < 0.01$) hands.

Discussion

In the present study, we have adduced evidence that (1) digit lengths fluctuate across the normal menstrual cycle, tending to be higher in the follicular phase and lower at or after ovulation, (2) digit length, particularly 2D length, exhibits lateral asymmetry with the dominant hand showing greater 2D lengths in dextral individuals, and (3) differences in length between digits 2D and 4D in dextral subjects are focused on the non-dominant hand. Findings suggest further that finger lengths display little inter-individual variability and that 2D:4D length ratios are tightly correlated or regulated across the cycle. Finally, there is evidence that patterns seen in the normal cycle are perturbed in those taking oral contraceptives. These perturbations affect both the left and right hands and reduce the relative differences between 2D and 4D expressed in terms of the 2D:4D ratio, 2D-4D difference and DTE. Although more caution should be exercised because of the smaller sample sizes, oral contraception also increased the difference between 2D and 4D in both hands leading to the difference in the dominant hand becoming statistically significant.

The value of different measures

Our findings provide evidence that inter-individual variation in finger lengths is small (typically, CV values fall in the range 6–7% of the group mean) and does not fluctuate during the menstrual cycle. Moreover, inter-individual variation was reproducibly lower for 2D:4D ratios (up to 3–4%) and this is in reasonable accord with previous values for females (e.g. Buck et al. 2003; Manning et al. 2005). This observation may simply reflect the fact that finger lengths are positively correlated but it might also indicate that the ratio is being regulated directly, or indirectly, by the investment of biological, possibly genetic, effort. Whatever the explanation, a positive benefit of lower variability is that the 2D:4D ratio offers a more reliable estimator in terms of overall precision. Certainly, it offers improved discrimination for a given sample size compared to the 2D-4D difference (CV values 200–800%) or DTE (CV values 200–5700%). Clearly, DTE and 2D:4D differences are very noisy estimators and not ideally suited to detecting subtle differences between groups. In this study, they did not reliably detect differences over the menstrual cycle.

Fluctuations over the menstrual cycle

There is much evidence to suggest that androgens and oestrogens play a key role in the development of digit lengths and the 2D:4D ratio. Studies on levels of testosterone (T) and oestrogen (O) in amniotic fluid following amniocentesis (Lutchmaya et al. 2004) have shown that, for the right hand only, there is a inverse relationship between the 2D:4D ratio and the T:O ratio which is independent of sex. Thus, individuals with higher 2D:4D ratios tended to show lower testosterone levels relative to oestrogen levels. No such relationship was observed for the left hand. Other investigations on females have noted positive correlations between 2D:4D ratios and levels of LH (right and left hands), oestrogen (right hand only) but not FSH (Manning et al. 1998). These observations have led authors to suggest that the 2D:4D ratio in the right hand may be more sensitive to hormone ratios and this notion is supported by more recent studies showing that 2D:4D ratio is correlated with salivary oestradiol levels (McIntyre et al. 2007).

The involvement of oestrogen is strongly supported by the presence of oestrogen receptors in osteoclasts and osteoblasts (Buck et al. 2003) and evidence that oestrogens can modulate *HOX* gene expression (Taylor et al. 1999).

Likewise with testosterone, evidence that it is positively correlated with many traits including autism and mental rotation, which are also negatively correlated with the 2D:4D ratio, are suggestive of its role in 2D:4D development (Manning et al. 2001; Manning & Taylor, 2001).

This study has demonstrated significant fluctuations in 2D length (both hands), 4D length (right hand only), 2D:4D ratio (left hand only) and DTE (right hand only) across the menstrual cycle. Lateral differences in 2D and 4D lengths also showed cyclical variation. In the dominant (right) hand, 2D lengths tended to increase during the follicular phase and decline around ovulation or soon after. In the same hand, 4D lengths fluctuated in a similar fashion such that no changes in 2D:4D ratios or 2D-4D differences were detected. Significant fluctuations in DTE were detected with the smallest values being found just before mid-cycle. In the non-dominant hand, the trend was also for 2D lengths to increase during the follicular phase and decline around ovulation. 4D lengths appeared to vary in a similar way but the pattern was not consistent and no significant differences were detected. However, there was significant cyclical variation in 2D:4D ratios with higher values tending to be seen in the follicular phase. No changes in 2D-4D differences or DTE were detected.

Left–right differences in 2D and 4D lengths also fluctuated over the cycle. Whilst 2D length in the right hand exceeded that in the left at all stages of the cycle, the smallest lateral differences occurred around ovulation. In the case of 4D, greater differences were seen before ovulation and smaller differences were detected in the luteal phase.

A rigorous interpretation of these fluctuations is made difficult for various reasons. First, we relied on self-reporting of cycle status and had no independent physiological estimates of hormonal levels. Therefore, it is possible that cycle stages were not fully synchronised between individuals. Second, studies of hormone levels have suggested not only left–right differences in the hormonal sensitivity of digits (Lutchmaya et al. 2004) but also different correlations between hand side and nature of the hormone (Manning et al. 1998). On the basis of previously-reported relationships, we might predict that the right hand would be more sensitive to rising oestrogen levels and both hands to rising LH levels. To some degree, our data on 4D lengths in right (dominant) and left (non-dominant) hands are consistent with these predictions given that oestrogen and LH levels rise during the follicular phase and decline following ovulation.

Left–right asymmetries in finger lengths are also reported to vary during the cycle with asymmetries increasing and then decreasing markedly at ovulation (Manning et al. 1996; Scutt & Manning, 1996). Again, our values on 2D and 4D lengths and 2D:4D ratios in left and right hands are consistent with a decrease in lateral asymmetry around mid-cycle.

The changes in finger lengths may occur at the level of bone and/or soft tissues. For example, both osteoblasts and osteoclasts bear oestrogen receptors (Buck et al. 2003) and water movements in the uterus and oviducts are known to be influenced by the effects of oestrogen and progesterone on aquaporin water channels (Jablonski et al. 2003; Branes et al. 2005; Lindsay & Murphy, 2006). Uterine expression of aquaporins changes during the menstrual cycle (He et al. 2006) and aquaporins are expressed in human epidermis (Sougrat et al. 2002).

Fluctuations in those taking oral contraceptives

In the current study, significant fluctuations in 2D length (both hands), 4D length (both hands) and 2D:4D ratio (right hand only) were detected in those practising birth control by oral contraception. In the right hand, 2D lengths tended to increase during the follicular phase and decline around mid-cycle or soon after. In the same hand, 4D lengths fluctuated in a similar fashion although changes in 2D:4D ratios were observed. No 2D-4D or DTE differences were detected. In the left hand, the trend was also for 2D and 4D lengths to increase up to mid-cycle. No significant differences in 2D:4D ratios, 2D-4D differences or DTE were detected.

Lateral differences in 2D and 4D lengths also showed cyclical variation. Whilst 2D length in the left hand now exceeded that in the right at all stages of the cycle, the smallest lateral differences occurred before mid-cycle and pre-menstruation. A similar pattern was observed in the case of 4D lateral differences.

Lateral differences

For those not taking oral contraceptives, we found significant lateral differences in all variables in 2D finger length but not in 4D length. Consequently, the lateral asymmetry in 2D:4D ratio, 2D-4D difference and DTE appeared to be due solely to the greater length of 2D in the right compared to the left hand. Previous studies have emphasised the fact that 2D:4D differences in different contexts are often associated with the right hand (Manning et al. 1998).

This pattern of lateral differences was not reproduced in the group taking oral contraceptives. Although the significant lateral differences in 2D finger length were still present, the greater lengths were seen on the left (non-dominant) side and not on the right. Furthermore, no lateral differences were found for other variables.

2D vs 4D differences

In the group not on oral contraceptives, no significant differences in length between 2D and 4D were detected in the right hand but 4D length was greater in the left hand. For those practising birth control, 4D was greater than 2D length on both sides. These findings provide further evidence that the use of oral contraceptives may perturb normal lengths and relationships.

Concluding remarks

Present findings reinforce the utility of photocopy images to determine digit lengths and indicate that digit lengths and 2D:4D ratios offer very precise measures of greater discriminative power than 2D-4D difference or digital tip extent. Our demonstration of differences in digit lengths across stages of the menstrual cycle underlines the advisability of taking the stage of the cycle into account when taking digit measurements from pre-menopausal women. In future studies, it would be preferable to correlate digital length changes with more direct measures of hormone levels during the menstrual cycle (with and without contraceptive pill useage). Our studies on the use of oral contraception are difficult to interpret fully because the use of different types of contraceptive pill could lead to different biological and confounding effects. This possibility requires further investigation.

Finally, the menstrual cycle, and the use of oral contraceptive pills, are known to influence cognitive abilities in women. Those in the luteal phase of the menstrual cycle tend to score lower in spatial ability tests than those in the follicular phase (McCormick & Teillon, 2001). These effects are not related to stress as measured by salivary cortisol levels. The observations are supported by assessments of functional cerebral asymmetry in which hemisphere performance was tested in terms of aural responses to musical or verbal cues (Sanders et al. 2002). It was found that performance of the right hemisphere increased as oestrogen levels declined. Responses are also affected by oral contraceptive usage. Those in the luteal phase of the menstrual cycle also tend to score lower in spatial ability tests than those on oral contraceptive pills (McCormick & Teillon, 2001). These and other observations suggest that absolute and relative digit lengths may serve as practical proxy measures of behaviour and of health or disease status.

Acknowledgements

We are grateful to the students who contributed to this study.

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